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## PHOTOREFRACTION OCULAR SCREENING DEVICE AND METHODS

### TECHNICAL FIELD

The present invention relates generally to the field of ocular examination. More particularly, the present invention is directed to a photorefraction ocular screening device employing novel methods of pupil detection and refractive error analysis for assessing vision and corresponding disorders associated with the human ocular system.

### BACKGROUND

The basic function of a photorefractive device is to collect and analyze ocular responses to light stimuli. Light from an external source enters the eye through the pupil and is focused to create a small illuminated spot on the retina. Some of the light from this retinal spot is returned out of the eye through the pupil after interaction with different layers of the retina. The pattern of light exiting the pupil is determined by the optics of the eye and is dominated by an examinee's refractive error (focusing errors of the eye).

Unlike fundus photography, wherein a large area of the retina is illuminated and a camera is focused on the retina to image details of its anatomy, photorefraction does not directly image the retina or any other structures in the posterior segment of the eye. In photorefraction, images are obtained by focusing on the pupil to obtain the light pattern exiting the pupil—i.e., images are analyzed in the pupil plane.

In earlier known methods of photorefraction, typically only eccentric illumination (i.e., lights arranged outside a lens aperture of an ocular screening system) is used. This approach has limitations and can often result in refractive error determinations that are inaccurate or ambiguous, particularly since eyes with different refractive errors can have similar responses under a given illumination. Classic photorefraction using eccentric illumination alone generates a “crescent-like” reflex in the pupil plane, the edges and domains of which must be determined for purposes of correlating the pupil response with a refractive error. When using eccentric or decentered illumination alone, determination of the crescent boundary is a difficult task. In addition, the determination of pupil size and location is often compromised by not having sufficient pupil edge data (due to dark edges) for accurate pupil circle fitting.

Accordingly, there exists a need to provide improved methods of conducting photorefraction-based ocular examinations.

### BRIEF DESCRIPTION OF THE DRAWINGS

The objectives and advantages of the present invention will become apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, wherein like reference characters refer to like parts throughout, and in which:

FIGS. 1A and 1B illustrate cross-sectional views of an exemplary photorefraction ocular screening device, in accordance with embodiments of the present invention.

FIGS. 2A and 2B illustrate an LED array with respect to the limiting aperture of a lens component coupled to an image capture component of the photorefraction ocular screening device, in accordance with embodiments of the present invention.

FIGS. 3A and 3B illustrate a comparison of reflexes at the pupil plane, respectively, from eccentric illumination alone

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and decentered plus coaxial illumination, in accordance with embodiments of the present invention.

FIG. 4A illustrates three primary axis-conjugate meridians, and FIGS. 4B-4D provide tables illustrating paired LED stimuli that may be selected in one of the three primary meridians at varying degrees of decentrations, in accordance with embodiments of the present invention.

FIG. 5A illustrates two supplementary meridians, and FIG. 5B provides a table illustrating paired LED stimuli that may be selected in one of the two supplementary meridians at varying degrees of decentrations, in accordance with embodiments of the present invention.

FIG. 6 illustrates selection of a co-axial LED stimulus without pairing to a decentered LED stimulus, in accordance with embodiments of the present invention.

FIG. 7A illustrates emitted and refracted light paths between an examinee and the photorefraction ocular screening device, and FIG. 7B illustrates full-frame dimensions of an image capture received at the photorefraction ocular screening device, in accordance with embodiments of the present invention.

FIG. 8A is a flowchart illustrating a general overview of an image acquisition and analysis process engaged in by the photorefraction ocular screening device during an ocular examination, and corresponding FIGS. 8B-8D are flowcharts illustrating sub-processes associated with three phases executed during image acquisition in the process of FIG. 8A, in accordance with embodiments of the present invention.

FIG. 9 is a flowchart illustrating a process engaged by the photorefraction ocular screening device associated with pupil acquisition, distinguishing full frame operations and pupil candidate operations, in accordance with embodiments of the present invention.

FIG. 10 illustrates an optimized pupil filtering kernel, in accordance with embodiments of the present invention.

FIG. 11A illustrates a dual-method approach for binarizing a pupil candidate to identify pupil edge pixels, FIG. 11B is a flowchart illustrating a process engaged by the photorefraction ocular screening device using the dual-method binarization approach of FIG. 11A, and corresponding FIGS. 11C-11E illustrate specific aspects of the dual-method binarization approach comprising a pixel intensity method and a pseudogradient method, in accordance with embodiments of the present invention.

FIG. 12 is a flowchart illustrating a process engaged by the photorefraction ocular screening device for determining refractive error along a meridian, in accordance with embodiments of the present invention.

FIG. 13 illustrates a glint interpolation area, in accordance with embodiments of the present invention.

FIG. 14 illustrates rotation of a pixel extraction region, in accordance with embodiments of the present invention.

FIG. 15 illustrates pupil image ratioing, in accordance with embodiments of the present invention.

FIGS. 16A-16C illustrate, respectively, computation of an axis-conjugate ratio, generation of a profile slope and generation of a PCA data vector, in accordance with embodiments of the present invention.

FIG. 17A provides a table of eccentricities associated with stimuli in each of the meridians, and FIGS. 17B-17C are, respectively, exemplary calibration curves for each of eccentricities and a corresponding aggregate calibration error curve to determine refractive error, in accordance with embodiments of the present invention.

### DETAILED DESCRIPTION

The present invention is directed to a photorefraction ocular screening device employing methods for ascertaining an